Building and Environment 153 (2019) 128–137

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Is the Australian construction industry prepared for climate change?

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ARTICLE INFO

Keywords:
Climate change
Adaptation
Mitigation
Construction
Australia
Adaptive capacity
Preparedness

ABSTRACT

Research examining the construction industry demonstrates that it is the source of a large percentage of global greenhouse gas emissions, subject to future climate change risks, and that there is limited evidence of adaptation. This paper explores the preparedness of the Australian construction industry to adapt to climate change risks, through twenty-one key stakeholder interviews. The interviews addressed participants' perceptions of the industry's: climate change risk awareness, analytical capacity to address climate change risk, and current actions to address these risks. The main risk participants identified was extreme weather during construction (e.g. heat and wind) with impacts for occupational health and safety, supply chain reliability, project delivery delays, and profit. The impact of these risks was somewhat down played. While a high level of perceived analytical capacity to respond to climate change was observed, real action was limited by systemic, outdated regulations, lack of client motivation, and perceived costs. The climate change actions which were undertaken were predominantly climate change mitigation activities, largely focussing on organisational processes, rather than adaptations to built form. The results indicate that if Australia's built form is to be well adapted to climate change, greater preparedness to facilitate tangible and systemic actions to address climate change risk in the Australian construction industry is needed. Specifically, interviewees responses imply that increased awareness of the impacts of climate change, better translation of existing solutions into practice, and regulatory reform are needed.

1. Introduction

The effects of climate change are becoming increasingly evident worldwide. The projected future impacts of climate change pose further, and more extensive changes in the form of storms, floods, rising sea levels, and temperature increases [1,2]. These changes will have significant implications for how societies function, affecting both built and natural environments, and the health and wellbeing of those that depend on them.

Two degrees of warming is viewed as the 'threshold for irreversible climate change' ([3] p.21). Thus, limiting warming to less than two degrees is required and is only possible if atmospheric concentrations of CO_2 (equivalent) in the year 2100 are limited to around 450 ppm [4]. Practically, this requires 2050 greenhouse gas (GHG) emissions levels to be 40–70% lower than 2010 levels [4], a goal that is addressed internationally through the United Nations *Framework Convention on Climate Change*, and the *Paris Agreement* [5]. Alongside the efforts to limit global warming, the *Paris Agreement* recognises that significant adaptation to the impacts of an inevitable two degrees increase in average temperature are necessary. Thus, actions that address both adaptation (action to minimise climate change impacts) and mitigation (action to reduce greenhouse gas emission) are essential to reduce risk, harm and cost.

As highlighted by the Intergovernmental Panel on Climate Change's (IPCC's) *Special Report on 1.5 degrees of warming* [2], achieving this goal will require a transformative shift to the way that all cities, and the sectors and professions therein, develop and function [6]. The construction industry[1] is a key contributor to GHG emissions. In 2010, 6.4% of total global GHG emissions were attributed to 'buildings', and an additional 12% of indirect emissions from energy and heat production, are linked to buildings ([4] p.9). The construction sector also influences other emission sources indirectly, including emissions from transport use, and across the whole life cycle of construction [7]. Simultaneously, the industry faces major risks as a result of the projected impacts of climate change [3,8–10]. In order to minimise these risks, building design and construction practices will require significant change [3]. The construction industry therefore has significant potential to reduce emissions and to facilitate adaption to climate change.

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[1] Defined as consisting of: those businesses mainly engaged in the construction of residential and non-residential buildings (including alterations and additions), engineering structures and related trade services. ABS. (2010). Feature Article: statistical overview of the construction industry, Viewed 3/11/17 at: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1350.0Feature+Article1Oct+2010

https://doi.org/10.1016/j.buildenv.2019.02.008
Received 28 November 2018; Received in revised form 3 February 2019; Accepted 4 February 2019
Available online 25 February 2019
0360-1323/

Table 1
Climate change impacts and potential risks for the construction industry.

Category of climate change	Predicted climate change risks [1]	Implications for the construction industry from Ref. [30]; plus authors' own in *italics.*
Temperature changes	- Higher average temperatures - Increased frequency of extreme heat days - Increased frequency of heat waves - Increased risk of bushfires - Increased drought conditions in some areas affecting water availability	- Increased demand for electricity in summer - Peak power use outage possibilities - Loss to productivity due to heat related fatigue of workers - Potential restrictions to building works in bushfire prone areas - Difficulty in obtaining insurance - Damage to construction equipment - Higher construction costs and construction management issues associated with water shortage - Restrictions to water use impacting landscaping - Projects may no longer be feasible given restricted access to water, electricity, and safety - *Management of site labour in extreme temperature conditions* - *Additional costs associated with changes required for materials and onsite construction*
Extreme weather events	Increase in occurrence and intensity of: - cyclones - hailstorms - wind - storm surges - flooding (riverine and sea)	- Delays to construction time lines including through disruptions to the supply chain - Damage to construction tools, materials and buildings in progress - Rising costs of insurance, and possible inability to obtain insurance - Increased costs associated with construction to mitigate against these impacts - Damage to essential services and infrastructure - Damage to existing built assets – costs of repairs - *On site safety implications for workers*
Sea level rise	Projected sea level rise of 0.17–0.38 m by 2065, and between 0.26 and 0.82 m by 2100.	- Increase cost of construction - Increased time for construction - Restrictions on permits and locations for development - Damage to existing built assets - *Increased exposure of low-lying areas (not inundated) to intermittent flooding and associated direct, indirect and consequential losses; insurance issues; and operational and management costs.*

Much of the research in the construction industry has focused on knowledge development and technology to inform the stabilisation of GHG emissions within the industry (e.g. Refs. [11–13]. There has been limited published research assessing the industry's preparedness and capacity to adapt to climate change risks. Of this, most was undertaken in the United Kingdom (UK) [14,15]. Research investigating broader climate change adaptation issues in the construction sector includes research in: Japan – a review and position paper about adapting to the urban heat island effect [16]; Canada – the presentation of climate change impacts by region and discussion of the implications for the built environment [17]; and in the USA – the need for building regulation to consider climate change hazards [18]. Research conducted in the UK [19] has found that traditional design and construction processes prevail, despite the imperative to address climate change, suggesting a limited capacity of the industry to adapt to climate change. Research conducted on the construction industry in Australia by Ref. [20] found that a major barrier to climate change action was the current regulatory context. These studies are further discussed in section 3 of the paper.

This research aims to investigate preparedness to adapt to climate change risk in the Australian construction industry through a qualitative study of key actors. Moser and Luers' [21] framework for assessing preparedness to adapt to climate change risks is adopted to investigate this aim. Moser and Luers' framework was influenced by prior work conducted in the UK [22] and the USA [23], which found that for governments to address climate change risks, it is important for them to consider their *awareness* of climate change, whether they can *analyse* the impacts that climate change will have on their activities, and to consider the *actions* they are taking or could take in the future. Moser and Luers' [21] framework contains three components: 1) 'awareness' of climate change risks; 2) 'analytical capacity' to translate climate change risks into activities; and 3) 'actions' taken to address climate change risks.

In 2008, Tribbia and Moser [24] used this framework to assess Californian coastal resource managers' preparedness to address climate change risks and their information needs, through eighteen semi-structured interviews and 135 surveys. They found that with the exception of one or two interview respondents, none of the participants used future climate change projections in their current decision making. They found there was relatively good capacity to use current analytic tools such as GIS and maps. However capacity to use detailed forecasting and analytical tools was not as high, thus consultants were drawn upon for these types of climate change analysis activities. The results of the study published in Ref. [25] indicate that of the 135 survey respondents, half did not know whether their jurisdiction had started gathering information about climate change impacts, and 30% indicated they had. Overall, the findings of these two studies conclude that coastal managers and the public need more information about the impacts of climate change, to trigger the need for greater preparedness.

Moser and Luers' [21] framework has since been applied in other sectors and contexts. This has included: drinking water utilities [26], where interviews with 259 Californian utilities found awareness of climate change was high, yet analytical capacity was found to be limited. Over half of the utilities surveyed reported adaptation activities (ranging from reducing demand to seeking alternative sources of water) had been undertaken. The framework has also been expanded as an analytical tool to assess how climate change is addressed in the spatial plans of Indian cities [27]. That study found there were limited actions to address climate change issues, which followed from low levels of awareness, and moderate analytical capacity. Likewise, the framework was used by Tang et al. [28] to assess local land use plans in California. They found low awareness of climate change and little analysis in the plans they evaluated. Furthermore, the actions (policies tools and strategies articulated in the plans) were found to be highly varied between jurisdictions.

This paper adds to the extant body of work on preparedness to adapt to climate change previously undertaken in other sectors. It operationalises Moser and Luers' [21] framework to explore the extent to which the Australian construction sector is prepared to adapt to climate change risks, through the following research questions:

- Is there an awareness of climate change risks?
- Is there analytical capacity to address these risks?
- What actions have been taken to address climate change risks?

This paper begins by providing an overview of climate change

projections and the implications for the construction industry, before reviewing pertinent literature. A description of the research method is then provided before the presentation and discussion of results.

2. Climate change projections and implications for the construction industry

The risks attributable to climate change and their effect on the built environment have received attention in government, industry and academic publications (e.g. Refs. [1,9,29,30]. In order to provide context to the research reported here, Table 1 provides a summary of manifest climate change risks and their theorised implications for the construction industry. Despite this knowledge, limited research has been undertaken to understand the extent to which this knowledge translates into 'awareness', 'analytical capacity' and 'actions' [21] within the built environment professions.

In addition to the generalised implications detailed in Table 1, each of the risks will have specific implications for built environment assets and construction activities, depending on locational-specific climate changes.

3. Climate change adaptation and the construction industry

Internationally, limited work has been conducted to explore the preparedness of construction industry firms to adapt to climate change risks. Hence, the work reviewed here also draws upon studies of built environment fields relevant to construction e.g. house building and urban development. The review examines existing literature in terms of the three components of Moser and Luers' [21] climate change adaptation preparedness framework; *awareness*, *analytical capacity* and *actions*.

3.1. Awareness of climate change risks

Key investigations into climate change risk awareness in the construction and allied sectors include [31] qualitative study of climate change impacts on the UK house-building sector, [32] global review of adaptation to climate change from a business perspective, and Taylor et al.'s [37] Australian study of property developers and urban adaptation. Research shows that a key climate change risk for both the UK [31] and international building industries [32] are the financial implications of the effects of changing weather patterns on construction processes e.g. affecting timely completion and health and safety considerations on site. Changes required to adapt to climate change within the sector were perceived to include innovation in construction processes; risk sharing; regulation; and consumer demand [31,32]. Taylor et al.'s [37] survey of the members of the Urban Design Institute of Australia identified that the greatest perceived risks resulting from climate change were upgrading building design standards, costs of insurance, and subsequent decreasing property values. They also found that developers were less likely than non-developers to agree that future benefits outweigh short-term costs of changes to practice.

3.2. Analytical capacity to address climate change risks

Gul and Menzies' [19] analysis of the UK residential building sector found that analytical capacity to address climate change was limited by the regulatory environment. There have been broad critiques of the limitations of current regulation to addressing climate change across diverse geographical contexts [18,20,33,34]. Eriksen et al.'s [35] study investigated the prefabrication housing sector in Norway and its implications for climate change adaptation. They found that devolution of former public responsibilities and associated new regulations are threatening adaptive capacity by weakening the relationships between public and private actors. They believe this is potentially resulting in a loss of locally specific design knowledge that enables builders to respond to changing climatic conditions. Taylor et al.'s [37] focus group research identified that developers were unclear about the practices they were expected to adopt to address climate change risks.

3.3. Actions to address climate change risk

Recent analyses in the UK [36] and Australia [37], suggest that climate change adaptation actions in the built environment appear to be taking place predominantly in the public rather than the private sphere. This research also indicates that in discussing adaptation to climate change, interviewees tend to focus on mitigation rather than adaptation [14,31,33]. Morten et al.'s [14] study focused on the UK building industry. Their survey research found that there was a high level of concern about climate change, and a belief that current practice was not adequate, thus new processes were required to address climate change. In comparison to conventional drivers of change (e.g. technological market, regulatory) climate change sensitivity was not perceived or treated differently [38]. This finding is consistent with other studies including by Hertin et al. [31] who found that climate change was just one factor amongst many influencing strategic decision making, and that it was seen as a future issue, not a present one. A similar finding was revealed in Taylor et al.'s [37] Australian study which found that in comparison to other issues, climate change was considered a low priority.

This review of literature indicates there are some gaps in the understanding of climate change adaptation in the construction industry, with limited direct studies exploring preparedness to adapt to climate change risks, and limited research in the Australian context. This paper addresses these research gaps.

4. Research method

4.1. Research context – the Australian construction industry

The Australian construction industry is comprised of three sectors: residential; non-residential and engineering [39]. Activities in the construction industry are regulated by the National Construction Code [40] which is implemented by state, territory, and local levels of government. The National Construction Code sets minimum standards for the design, construction and performance of building and plumbing. Further information about the construction industry and its regulatory context can be found in Ref. [20].

4.2. Participant recruitment

An in-depth, qualitative research method was employed to provide a detailed understanding of preparedness to adapt to climate change risks in the Australian construction industry. In order to include a diversity of views, the sample was purposively recruited from the three construction sectors noted above: residential, non-residential and engineering. Participants were sought from multiple companies of diverse size. To begin the recruitment process, a list of companies was compiled, and a 'construction manager' and 'sustainability manager' or equivalent (e.g. someone with the responsibility for environmental or sustainability issues within the firm) was identified, if present in the company. Some companies did not have a sustainability manager or equivalent. This list was used to invite individuals to participate in the research. Additionally, a key actor from an industry association representing each of the three construction sectors was interviewed. In total twenty-one interviews were conducted between February and June 2017 (see Table 2 for details). This number is in line with qualitative research sampling procedures [41], and is consistent with similar, published studies on the topic [31,38].

Table 2
Number of interview participants across construction sectors and interviewee types.

Sector/Interviewee Type	Sustainability Manager	Construction Manager	Industry Association	Total
Residential construction	RCSM[a]: 3	RCCM: 3	RCIA: 1	7
Non-residential construction	NRCSM: 5	NRCCM: 4	NRCIA: 1	10
Engineering construction	ECSM: 3	ECCM: 0	ECIA: 1	4
Total	**11**	**7**	**3**	**21**

[a] Acronyms are used in the reporting of results to indicate interviewees' sector and type.

4.3. Interviews

The interviews included a series of questions about preparedness to adapt to climate change risks, employing [21] framework: 'awareness', 'analytical capacity', and 'actions,' adapted for application to the Australian construction industry context. Question design was informed by empirical studies employing this framework [24]; and [25]. Questions about barriers to adaptation (reported in Ref. [20]) and information sources (reported in Ref. [42]) were also asked. Participants were based in Canberra (1), Sydney (7), Melbourne (12) and Perth (1). Interviews were predominantly conducted face to face, except for three that were conducted via telephone. The interview duration ranged from 17 to 61 mins. Each was digitally recorded except for one interviewee who did not consent. In that case, detailed notes were taken by the interviewer.

4.4. Data analysis

The interviews were transcribed and analysed in three stages using NVivo 12 for Windows. The first stage involved: actively reading the transcripts, simultaneously listening to the recordings (to ensure the speakers meaning is understood e.g. considering inflection); correcting any transcription errors; and coding aspects of the responses relevant to each of 'awareness', 'analytical capacity' and 'actions' [21]. The process of coding is used in qualitative research to organize the vast amounts of text into a smaller number of categories [43]. Data relevant to more than one aspect were coded as such, while data that did not contribute to answering any of the research questions were not coded.

The second stage of analysis involved qualifying the data that had been collected under each code (node) into sub categories ('coding-on') [44]. For example, within the node 'capacity', data that described self-reported 'excellent' capacity was coded separately to those which described 'good', 'fair' or 'poor' capacity. The third stage comprised a second coder who reviewed the content of nodes and sub-categories and where appropriate, discussed coding decisions and either re-coded or coded-on to ensure that all content had been accurately coded, thus verifying content in codes. Once coding was completed, the themes that emerged within each of [21] three components (awareness, analytical capacity and actions), were synthesised. While frequency counts for codes were collated to help determine dominant themes, the critical component of the analysis was the qualitative synthesis of individuals' responses within codes. The results are presented below.

5. Results and discussion

5.1. Awareness of climate change risks

Interviewees were asked about their awareness of climate change risks to the following: during construction, post completion of construction, for their company, and the for the broader industry. All interviewees were aware of climate change and there was no evidence that any participants doubted that climate change is real. Interviewees stated for example that 'we have a pretty clear view that climate change is a massive problem' (NRCCM1), and that the evidence consistently suggests that 'it's going to get hotter' (NRCIA1). One stated, 'I don't believe that anybody, certainly in our industry, doesn't believe it's occurring' (ECSM1). An interviewee from engineering construction believed emphatically that there are no climate change deniers in his sector:

> … they get the shit burnt out of them [to be severely burnt by the sun] every day, right, and it's the hottest summer in five million years and what-have-you. You know, I think that, you know, personally, my experience with the civil engineering thing is that they do, they feel it … they're not in denial about it. (ECSM1)

Despite this, interviewees felt that the level of understanding within the broader industry was not high, with several noting that certain concepts were far more accessible than was 'climate change'. For example, ' … if you ask half the staff in here, they'd go, 'What's climate change?' It's [only] a concept' (RCSM3). The challenges associated with understanding the implications of climate change meant that, despite acceptance of the existence of climate change, some organisations,

> … [don't] make any decisions at all, really at the moment. … It's certainly not discussed at our board level as, 'there's this big concern about climate change'. (NRCCM4).

Despite most interviewees stating that they personally believed that climate change was a phenomenon that needed to be addressed, the low profile that it took in decision-making, in contrast to the influential role of government, is well encapsulated by the following statement from an industry association representative.

> … we don't have a conversation, either internally or with our members, about whether climate change is real. Our role is to respond to government. So if the government sets an agenda and then says this is what we're going to do, that's what we're dealing with. It's neither mine or the association's role to say that it is or isn't real. We just don't go there. (RCIA1)

5.1.1. Construction process climate change risks

The dominant climate change risk identified during the process of construction was inclement weather – principally heat and storms (Table 3). The inclement weather risks identified mainly included effects on workers, construction delays, and the subsequent financial implications, and is demonstrated by the following quote:

> I would say OH&S [occupational health and safety] is a big one for

Table 3
Identified climate change risks during construction.

Risk identified	Number of interviewees	Number of mentions
Occupational health and safety of workers due to weather events caused by climate change	11	40
Materials (quality and supply)	9	16
Waste management	4	7
Compliance	4	5
Energy	2	2
Other weather impacts of climate change	2	13
Preparedness to pay	1	5

us. You know, increased intensity of storms. There's going to be more wet weather. That's going to impact our programme, impact ability to deliver projects on time, and on budget. (NRCSM1)

The identification of weather as a risk to construction processes and worker safety is consistent with previous research conducted by Ref. [31] in the UK house building sector. Despite mentioning inclement weather as a risk attributable to climate change, many interviewees expressed an expectation that the industry has adapted and would be able to continue to adapt through innovation of existing processes. Yet, the weather-related impacts of climate change were acknowledged to be associated with a high financial risk to costing of projects. Interviewees talked of the need to be cost competitive in pricing projects, but also to allow for potential costs of weather related impacts and construction disruptions.

The second most frequently identified construction process at risk was ‘getting materials’ (ECSM1), that are of a suitable quality. Interviewees spoke of their concerns about climate change impacts disrupting the supply chain. For example, one interviewee stated that climate change would,

… impact the supply change, it means that there will be less certainty around materials supply, and that will again impact our ability to deliver the buildings in the time and the price that we've stated. (NRCSM1)

5.1.2. Climate change risks to completed projects

Interviewees were aware of risks attributable to climate change relevant to completed projects (Table 4).

Several interviewees identified uncertainty over the adequacy of design standards to address climate change weather impacts, adherence to standards, and questioning whether buildings and other infrastructure would be resilient to flooding or wind, or would perform as expected under increased heat load. These are important considerations, given research in the UK context of house building identified the potential liability for climate change related malfunction or damage to houses post construction [31]. When speaking about completed projects, six interviewees mentioned the importance of the climate change-mitigating role that projects could play, but that such benefits might be put at risk due either to tenant behaviour (‘ … you get somebody that uses the toilet 18 times a day and takes a 30 min shower; there's nothing that we can do about that’ (NRCSM1)) or poor design, and that these could compromise energy or water efficiency and security.

… if you've got, you know, 15 hot days in a row your cooling towers are running overtime burning through water, or chillers are using that much energy. (NRCSM1)

Thus, as this interviewee stated,

Plenty of five star buildings are being built but they're not operating as five star because nobody's paying attention to optimising their … users' behaviour … (NRCCM1)

Similarly other interviewees acknowledged that if, for whatever reason, infrastructure failed to play a mitigating role, then …

… the way they're designed just exacerbates the problem. And I think that that's the risk we fail to really pay a lot of attention to …. we won't actually do anything about the root cause. (NRCSM2)

Accountability from the constructor's perspective varied, with a residential construction sustainability manager stating that their company was ‘ultimately responsible’, because they were ‘the face that the client sees’ (RCSM2). In contrast, interviewees from engineering construction felt that this risk was minimised by ‘working with the client to ensure they're across what you're taking into account and responding to’ (ECSM1). Another stated that beyond the defects liability period ‘you're done and dusted and you're out of there’ and so they didn't think ‘there's much risk at all’ (ECSM2). Consequently, there are a variety of perspectives on who is ultimately responsible for addressing climate change risk related to completed products. This will likely become an issue of greater importance as climate change events affect property and its values [37,45] and as parties seek related damages to recoup losses.

Table 4
Identified climate change risks for completed products.

Risk identified	Number of interviewees	Number of mentions
Climate change related weather impact to constructed product	10	29
Heat load	9	14
Energy sources and efficiency	6	13
Water security and efficiency	4	5
Other	2	4

5.1.3. Risks to the construction industry

Eleven interviewees identified risks to the construction industry as a whole, and tended to reiterate the risks that were relevant to particular phases of product delivery. The combination of ensuring delivery of products that were resilient to weather extremes in the face of both uncertain supply and increasing cost of materials were cited as risks to profit margins. However, again there was a general understanding that these would be ‘transitional costs that … result in better performance’ (RCSM2) and that most of the industry would be able to adjust to these, except perhaps for the,

‘Mum and pop’ contractors [with just] three excavators and a couple of trucks … because all he's trying to do is to operate from a day-to-day perspective. (ECSM1)

Interviewees were generally of the opinion that … ‘once that transition is made, I guess it's the way it is’ (RCSM2). Due to an expectation that the transition phase could be responded to, one interviewee stated that they were,

…hesitant to say that [climate change] poses a risk to the industry as such [but] it changes it, it changes what we build and potentially how we build. (NRCSM3)

Yet, the risks to the industry were perceived in different ways in the different sectors. When examining the residential construction sector as a whole, it was noted by RCIA1 that,

the bulk of residential members have little to no interaction with the concept of climate change in their business operations. (RCIA1)

RCIA1 went on to discuss that from a residential context, unless its written in the Building Code, action is not going to occur at this level in the residential sector. This was noted by many interviewees, who questioned the adequacy of the Construction Code to address climate change (as reported in Ref. [20]). A lack of clear policy and consistency across jurisdictions, impacts the industry's understanding of climate change risk and of who should take steps to address it:

… it's unclear from the Federal government what they actually want of it [adaptation to sea level rise] and what role they have in guiding. Like, sea level was a big issue for us five years ago. It was the topic of the moment. The Feds [Federal government] put a massive amount of money into the adaptation kind of story and research. But they spent five years doing research and then got to the end of it and go well what do we do with it now. And we had one workshop and that was the end of it. (RCIA1)

5.1.4. Climate change risks to their organisations

When asked about the risk that climate changed posed for their

organisations, most interviewees raised similar issues to those mentioned above, but generally downplayed these risks as they felt their own organisations could adapt to them albeit after a period of transition. In doing so, the residential and non-residential industry association representatives indicated that their member base would remain, because while 'they might have a harder battle getting some of the approvals and might lose jobs' they would 'always have demand, … always have somebody wanting a house built' (RCIA1) and that in regard to any increased responsibility to adapt, 'often that decision's taken out of their hands, …they're just building a product that someone's asked for' (NRCIA1). Others stated that they were not aware of any risks (RCCM1) or hadn't thought about how climate change would affect them because,

> it's a reactive industry and until a problem occurs, change doesn't occur so … I don't think that we see it as a risk. (RCSM3)

Overall, climate change risk seemed to be understated, if mentioned at all. There was a positive outlook that the risks could be dealt with, and that there would be long-term resilience to whatever short term impacts these risks may have at the organisational or industry level.

5.2. Analytical capacity to address climate change

To assess analytical capacity, a series of interview questions were asked, firstly whether participants translate information about climate change into a format that is relevant to their company's activities (following [24]); and secondly, what capacity their organisation has to understand climate change and translate it into information relevant to inform their key activities.

5.2.1. Translating information

Fifteen interviewees said that their organisation translated climate change information into projects (see Table 5), but the subsequent detail provided was often limited. Five respondents mentioned specific projects where they had taken on board a specific adaptation action, 5 others mentioned policies and procedures that had been developed to address and consider climate change. One respondent mentioned that policies were operationalised via procedures, which were in turn 'integrating into … business activities' (ECSM2) via for example, a management system:

> … once we have a policy … procedures around what our minimum expectations are … we'll attach the tools and knowledge, we load it up onto the management system … which is our bible … and it automatically goes to the projects. (ECSM1)

Other interviewees had in-house specialists (3), having developed their own expertise on, for example, energy efficient products, or had consultants or in-house experts capable of developing 'full blown resilience plans' that incorporated location-specific forecasts (NRCSM2). Such methods demonstrate the characteristics of 'adaptive capacity' identified in Hertin et al.'s [31] UK study.

Table 5
Translation of climate change risk information.

How information about climate risk is translated	Number of interviewees	Number of mentions
Projects	5	7
Policies and procedures	5	5
In-house specialists	3	3
Training, membership, accreditation	2	5
Build the economic case for action	2	3
Forums	2	2
Subscriptions	2	2
Into their management system	1	4
No translation	8	15

Similarly, climate change forums (2) were identified by interviewees from the industry associations who stated that when issues relevant to their members emerge, they 'talk internally about, do we need to have an agreed position?' (RCIA1). As the engineering construction industry association representative opined, when the government announces changes, the organisation draws on the knowledge and experience of experts across large construction organisations, to put a response into the workflow of the relevant working parties (ECIA1). For one interviewee, translating information about climate change was done by developing their own expertise in communicating the economic, as well as the environmental benefit of selected products and design,

> I'll sit in there [showroom] just one day a week and any clients or any staff that need my assistance to talk about energy efficiency, climate change, all that stuff, to understand stuff better, I'll be there for that face-to-face and that's a big step for us. (RCSM2)

Eight interviewees spoke of their limited ability to meaningfully translate information about climate change, with one of these noting that there seemed to be ample information about problems, but an absence of workable solutions,

> But, what I find with a lot of information is that they … just state an issue, as opposed to really trying to help: You know, that really having done the thinking … providing ways in which [techniques] can actually be adopted by industry. (ECSM2)

This reiterates the importance of knowledge translation and exchange programs [46,47] that ensure scientific information is presented in a format which can be applied by decision makers (e.g. the 'science-policy interface' [48]). Other challenges that interviewees experienced with translating information about climate change included a low level of influence on those employed to design and construct buildings, including an absence of a 'champion' (NRCIA1) and the fact that mandatory standards rarely called for any translated information to be enacted in designs (NRCCM2 and NRCSM4). Finally, interviewees whose organisation did not translate information about climate into a format that was relevant to the company's activities simply stated that there was 'very little appetite for it' (NRCCM3).

Overall there are similarities with the findings of this research, and that of Californian Coastal managers by Ref. [24]; albeit in a different built environment field. They found there was relatively good capacity to use current analytic tools such as GIS and maps. However capacity to use detailed forecasting and analytical tools was not as high, thus consultants were drawn upon for these types of climate change analysis activities.

5.2.2. Capacity to translate information about climate change into activities

Participants were asked about the capacity of their organisation to understand climate change and translate it into information relevant to their key activities. Of the seventeen interviewees who answered this question directly, two made comments indicating they felt their capacity was excellent, stating for example,

> … we have a really high impact and ability to make change … because we are not bureaucratic. We are [however], constrained by what the project has available to us. (NRCCM2)

This example highlights the inability to go beyond the client's scope, thus restricting the organisations' capacity to make changes that would result in a well-adapted product. Interview responses from outside this direct question were also considered. Overall, twelve interviewees' comments suggested that capacity was good or fair, and only four suggested poor capacity to understand and translate climate change information. One comment from a volume builder company interviewee indicated good capacity, but that this appeared to be rare within the industry due to insufficient economies of scale (RCCM2). Two interviewees who indicated that capacity was 'fair', stated that the

information that was ‘harder to come by was those little innovations that just are not communicated’ (ECSM1) and that such communication needed to be ‘really simple and clear’ (ECSM2), again, indicating a need for information to be translated into a format which is suitable for decision makers and implementers [46,47]. Another participant, while indicating limited capacity, also suggested that some decisions were common sense, and was of the opinion that regulation provides guidance:

> We'll really look to the codes to give us guidance I guess – because we're not the scientists – to really assess what those risks are going to be. (RCSM2)

In comparing answers to this and the previous question, overall there was a mismatch between interviewees' assessments of the extent to which they translated information about climate change and their *capacity* to translate it. One interviewee suggested that while capacity was good, a ‘trigger point for getting that intellect engaged’ was often lacking (NRCCM3). The reason for this mismatch is well encapsulated by the following interviewee:

> We've got no excuse; we've got some of the smartest people in the world around us so that's - that's why I said it's interesting you're looking at capacity as opposed to will. There is no shortage of capacity. (NRCSM2)

Overall, adaptive capacity was seen to be limited by the regulatory environment that the government of the day was creating, which did not facilitate sufficient actions to address climate change. This indicates that there is limited critique of the status quo, which is likely to make the transition to a well-adapted industry challenging. The results reported here are similar to that found in California in a study of drinking water utilities, where [26]; that found awareness of climate change was high, yet analytical capacity was limited. Over half of the utilities surveyed reported adaptation activities.

5.3. Actions to address climate change

Actions taken to address climate change risk are detailed in Table 6. Two of the construction companies interviewed had a strong organisational culture that supported action, albeit not necessarily related directly to climate change but to more strategies to cope with current changes and challenges in the sector.

Yet, only one firm, (NRCCM1 and NRCSM1) were able to talk proactively about climate change adaptation with clients, who often sought them out because of their reputation for implementing progressive actions in projects. In this case, organisational culture appeared to assist action on climate change, which supports the findings of Berkhout et al's [38] study that organisational culture was a key determinant of a company's ability to respond to climate change risks. Ten other interviewees recalled specific examples of action that their organisations had taken in response to the risks of climate change. These included mitigation (action to reduce greenhouse gas emissions) and adaptation (action to minimise climate change impacts), but with more mitigation than adaptation actions identified, a trend found in other studies [14,31,33]. A further nine interviewees gave very broad responses to the question about actions to respond to climate change by saying for example that they were ‘not sure’, or ‘probably’, or that there was not much occurring at the corporate level:

> It's probably not many on at corporate level. I'm sure there's a few on various different projects depending on what that project was, but nothing at a corporate level (NRCSM3).

The mitigation activities identified by interview participants included: technology powered by photo-voltaic solar (ECSM3), installing LED lights (NRCIA1), using materials with a smaller embodied impact, recycling building materials (RCCM2, NRCCM1) and pushing for high star ratings in new buildings (NRCCM1, RCCM1). Additionally, interviewees cited managing and reporting on energy usage and putting forward energy efficiency measures in tenders (NRCSM1), the use of alternative energy sources such as ‘gasification of paper waste and wood’ (NRCSM5), increasing the efficiency of transport and logistics (RCCM2, RCSM2), reviewing and recommending more efficient products to homebuyers (RCSM2), using economies of scale to increase the use of energy efficient technologies in developments (RCSM2), and trialling community-scale battery storage (RCSM1).

Adaptation actions identified by interviewees included: 1) construction product related issues: recycling water into potable water (RCSM1), using concrete that can set at a higher temperature (ECCSM1), the delivery of built assets with ‘resilience and adaptation plans’ in place (NRCSM2), investigating the use of waste water to irrigate parks - despite the lack of political support (RCSM1); and 2) OH&S responses for staff due to climate changes: providing safer working environments in the face of inclement weather (RCCM1), the use of technologies such as ‘different gear people can wear that's kind of got ice packs' (NRCSM). Prefabrication was also mentioned by several interviewees as a possible way to deal with inclement weather:

> [weather is] going to push a lot of construction into factories and prefab because you're not going to get a brickie out there laying bricks when you've got [inclement weather]. (NRCCM)

The actions identified by interviewees were mainly focused on activities that might affect the operational aspects of the organisation (like the consideration of health and safety); and project specific actions (innovative techniques that appears to be driven more by sustainability than climate change). Only one, NRCSM2, had made a specific reference to climate change through the development and delivery of ‘resilience and adaption plans’. These considered some of the implications of climate change and how this would be dealt with, and its relationship with the built product, and how it would be addressed. Some of the actions which were identified, included a degree of innovation, which is consistent with Hertin et al's [31] study. Most interviewees stated that their actions were undertaken to ‘ensure that we meet all our regulatory obligations’ (ECSM1). In fewer cases, actions were undertaken to intentionally stretch the standards that are required by legislation, regulations or codes. One example of such an action (adaptation) is

> They've got models for … 200 [year floods], and then they've got one for one in a thousand [year floods]. We looked at the project and reengineered it, so that it could theoretically survive the impact of floods. (NRCSM2)

This interviewee stated that this action was taken not because the company would be held liable if it did not, but because ‘it was in line with the company's core values' (NRCSM2). Again demonstrating the

Table 6
Actions taken to address climate change risk.

Action	Number of interviewees	Number of mentions
Policies and plans	7	11
Using resilient materials and technology	6	6
Researching materials and technology	5	8
Recycling materials	5	6
Energy efficiency	3	3
Building for extremes	1	2
Carbon neutrality	1	1
Increase water recycling	1	1
Meet regulations	1	1
Responsive building practices	1	1
Submissions to government	1	1
No action	2	2

importance of organisational culture for enabling climate change action. Actions taken by the industry associations included the widespread use and promotion of sustainability rating systems (for example) NABERS and Green Star ratings for commercial constructions. However, this was not seen as particularly challenging due to a strong impetus coming from the owners of such buildings and because the commercial market has 'kind of understood that it's a good thing to do' (NRCIA1). As another interviewee stated:

> … our clients are demanding that we provide them with a product that has a certain ISCA [Infrastructure Sustainability Council of Australia] rating and so in order to get that, our designs need to be cognisant of climate change and sustainability. (ECSM1)

Overall, the Engineering Construction sector interviewees appeared to have a more developed understanding of climate change specific risks. Additionally, those risks appeared to be embedded within organisational policy. Their clients were seeking out project details to address climate change and sustainability issues in order to obtain certain ISCA ratings, which could thus justify higher costs for the project pricing. This demand could be due to the nature of these infrastructure assets, being owned and managed by the client (e.g.) over longer periods of time, hence providing motivation to build for longevity and efficiency.

There was also a high level of expressed confidence with adaptive capacity, and a view that information about climate change was being actively and adequately incorporated into projects as a standard activity (ECSM1). The long-term management of the assets by the client was also seen as a contributing factor (ECSM1). The way in which they sought information to inform projects was also wider, given:

> if you think of the Australian construction industry, it lags typically …. you know, the UK and European industries, and the way they think so, so we draw from a number of sources there. (ECSM2)

Another type of action that representatives from the industry associations stated they undertake is making submissions to government reviews of policies and procedures, attempting to make the most of the opportunity to build resilience into the industry, while still ensuring that the industry's shorter-term interests are upheld (RCIA1).

The actions taken by those interviewed in this study are mainly actions related to the organisation internally, mostly focused on occupational health and safety and financial viability, project management and innovation, and strategic positioning. Many of these actions are being driven by something other than climate change. For example, the concerns for working in the heat, and innovative techniques to combat this, are motivated by current climatic conditions, and workers' OH&S and legislation. Project management that is responsive to weather extremes, be it heat, rain or inclement weather, is again something that is currently being dealt with and is a current risk to all projects. Rather, it was considered by many respondents to be an example of using current practice as a 'demonstration' of climate change adaption. It should be noted that a recent Australian government report [49] indicates that Australia's climate has warmed by just over 1 °C since 1910, and has seen an increase in extreme heat days, thus these present day actions are an adaptation to changing climate conditions. However, certain interviewees, specifically those from engineering construction and one of the non-residential construction firms, are looking more strategically at the challenges posed and how to position their organisations for change. One respondent stated it is an internal organisational policy function in addition to useful for promoting their capacity to clients.

These results indicate that the capacity to take action in response to climate change exists, but at present its implementation and drive is isolated to early adopters. Despite these positive signs, the barriers that are preventing increased awareness and capacity limit the ability of the broader industry to adapt. It was also apparent that the industry as a whole does not yet fully appreciate the risks implied by climate change and that this is limiting broader engagement and drive for action.

6. Conclusion

This paper has provided in-depth qualitative insights into the preparedness of the Australian construction industry to adapt to climate change risks. While all respondents stated they were aware of climate change, the climate change risks identified by interviewees were strongly related to current risks rather than future perceived risks. The risks focused on actual construction production, identifying risks associated with the processes (weather and OH&S related), post completion issues (serviceability and defects) related to building viability under changing climatic conditions in the absence of updated regulation, and provision as per client requirements. These risks related to existing risk frameworks in terms of processes, completion and client requirements and expectations, and were not considered to be new risks but an extension of those already being dealt with. The potential inability of organisations to conform with expected regulatory changes that are responsive to climate change was also identified as a risk, one which also led to industry wide implications. The risks that weren't well articulated were those that created a level of uncertainty or lack of ability to understand how the organisation, project or industry might be affected in the future. In these cases, it was apparent that there was a need for leadership from government, specifically for it to provide information and regulation to enable solutions and effect change.

Further, it was considered that the analytical capacity within the industry to mitigate and adapt to climate change challenges exists, but actions were limited to focus on currently experienced risks, rather than to specifically focus on the future risks posed by climate change. Many interviewees were confident that their organisations had adequate analytical capacity, yet there was limited evidence that this was translated into actions at the organisational level. Several types of constraints were identified to realising analytical capacity. These included the lack of legislative requirements, no client appetite, and high perceived costs. Another theme emerging from responses was the perceived industry disinterest for changing the status quo, and a lack of engagement with substantive climate change information and practical examples of adaptation and mitigation. Accompanying this was a low level of innovation in construction processes to address climate change at this stage. Overall there was a sense of a lack of willingness to address barriers to actions to address climate change through construction processes. This in turn was tied to limited government and regulatory impetus for change. Yet this was not the case for all interviewees, a small number of interviewees did advocate for climate change adaptation initiatives, and for a few, their organisational culture and mission allowed this to be facilitated, and so it was translated into tangible actions to address climate change at big and small scales.

Overall, more mitigation than adaptation actions were identified. Adaptation actions were dominated by activities for the benefit of their organisation e.g. to construction processes (e.g. prefabrication in a controlled environment), and less related to adaptation of the constructed products (e.g exceeding design standards to meet changing weather conditions), and may be a product of the fact that construction firms largely don't manage or occupy the buildings post construction. Actions to enable climate change adaptation and mitigation were predominantly piecemeal, and project based, rather than systematic. Actions were limited by policy constrains; and by the limited information about climate change available to key actors. This indicates that further work is needed to translate knowledge and information about climate change to a format that is useful to those in the construction industry.

This research has identified some key challenges for the future of the Australian construction industry if it is to reach its full capacity to address climate change. The three main challenges identified are: firstly, the inadequate understanding of the extent of risks posed by climate change and creating greater certainty around potential impact, from both a project specific process and an organisational perspective; secondly, the importance of assisting organisations to incorporate

adaption approaches within the firm and in projects through translation of risks, opportunities and guidelines; and finally, a review and update of construction standards to a point where they are sufficient to adapt built environments adequately to climate change (an issue discussed in further detail in Ref. [20]).

In the absence of regulatory reform there is little incentive for construction organisations adapt given cost implications. Creating regulatory reform could drive innovation in the sector both from a project and organisational perspective to meet the challenges within the regulations and in so doing create solutions for climate change adaption for the construction industry. It is pertinent to address these issues in the construction industry given the long life-time of built assets, and the difficulty to retrofit. Hence, a policy priority should be placed on addressing these identified needs. This paper adds to existing knowledge about preparedness to adapt to climate change risk. It applies Moser and Luers' [21] framework for assessing climate change risk preparedness: awareness, analytical capacity and actions. The results of previous research, and this study indicate challenges exist for climate change preparedness across a number of built environment/environmental management contexts, of which construction is one. Further research to advance action to address climate change across the built environment would be of benefit.

Funding

This work was supported by the 'Multiplex Research Program Award' 2016–2017. Multiplex had no involvement in the study design, or of the data collection, analysis and interpretation. Additionally they had no involvement in writing of this paper, or of the decision to submit this paper for publication.

Acknowledgements

We acknowledge Professor Valerie Fancis from the Faculty of Architecture Building and Planning who was a chief investigator on the research grant, and was involved in aspects of the study design. Additionally we acknowledge research assistance provided by Nicholas Harris-Baxter and Erryn McRae. We thank the anonymous reviewers for their insightful review of the paper.

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